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Comparison of concepts for possible future train integrity monitoring systems

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Abstract

In the railway sector, experts anticipate considerable reductions of costs by supplanting conventional infrastructure equipment with digitalised solutions. As a consequence, distances between trains can be reduced and track capacity increased, correspondingly.
The necessity to protect consecutive trains from lost vehicles of preceding trains leads to the need to monitor continuously the completeness of a train, which is also referred to as the integrity of a train, as intended in the European Train Control System (ETCS) level 3. The development of a safe corresponding train integrity monitoring system (TIMS) for Europe is still a challenge as many freight trains lack a continuous electrical line.
The purpose of this work is to give a short scientific overview of the main concepts for possible future TIMSs. For this, the publication is based on the work of the authors for the Swiss Federal Railways within the smartrail 4.0 industry programme in the year 2018. At that time, they conducted a study on approaches to TIMSs. As a result, they researched more than 600 publications. Now, in 2022, the authors realised an update of that study.
In this publication, the selection of concept classes for TIMSs grounds on that research work. The authors conclude that train integrity monitoring in Europe is currently based on axle counters and track circuits, so these two concept classes were chosen. In addition, the authors identified three main classes of possible future TIMSs: distributed acoustic sensing, end-of-train device and digital automatic coupling.

After that, the writers explain the selected five concept classes for TIMSs. As results, the advantages and disadvantages of the five concept classes for TIMSs are discussed. In the conclusion, the writers focus on the concept class of end-of-train devices as a bridge class to the concept class of the digital automatic coupling. For the authors, axle counters and track circuits are not of interest due to their difficulties of high infrastructure costs and especially the problem of fixed block section lengths, which does not support concepts based on the idea of moving block. From the authors' point of view, distributed acoustic sensing is still associated with significant open questions that will to be answered in the future.
Finally, the authors elucidate the contribution of this publication as a categorically new comparison of concept classes for possible future TIMSs, as a scientific publication comparing concepts for possible future TIMSs is still not findable.

Keywords: train integrity monitoring system, ETCS level 3, moving block, localisation.

1 Introduction

In the field of railway signalling, experts anticipate a significant saving of costs by supplanting conventional infrastructure equipment like signals and track vacancy detection systems with digitalised solutions [1]. Such a change includes the opportunity that block sections typically fixed by that infrastructure equipment can become moveable. Consequently, trains will be able to follow one behind the other within their braking distances. This reduction in distances between trains can lead to an increase in track capacity as an additional positive outcome [2].
On railway tracks without conventional signals and track vacancy detection systems, the need to protect consecutive trains from each other and especially from lost railway vehicles of preceding trains remains.
This results in the need to monitor continuously the completeness of a train, which is also referred to as the integrity of a train, as intended in the European Train Control System (ETCS) level 3 [2]. The development of a safe corresponding train integrity monitoring system (TIMS) for Europe is still a challenge as many freight trains lack a continuous electrical line [1].
The purpose of this work is to give a short scientific overview of the main concepts for possible future TIMSs with both their advantages and disadvantages as well as an evaluation. For this, the publication at hand is based on the work of the authors for the Swiss Federal Railways within the smartrail 4.0 industry programme in the year 2018 [1]. At that time, they conducted a study on approaches to TIMSs and train length monitoring concepts. As a result, they researched more than 400 intellectual property documents and almost 200 further publications [1]. Now, in 2022, the authors realised an update of that study and discovered that a compact scientific publication comparing concepts for possible future TIMSs is still not findable [3]. As a consequence, the authors would like to close that gap with the present publication.
The publication is structured as follows: After this introductory section with the purpose of this work, in the following section the authors expound the applied methods by describing the selection of concept classes for TIMSs as well as the associated concept classes for TIMSs themselves. Within the next section, the writers

elucidate the pros and cons of those concept classes. In the final section, the authors draw a conclusion and explain the contributing aspects of the present publication.

2 Methods

In this methods section, the authors elucidate the selection of concept classes for TIMSs and the associated concept classes for TIMSs themselves.

The selection of concept classes for TIMSs grounds on the research work on approaches to TIMSs by the authors in the years 2018 [1] and 2022 [3]. After researching a total of more than 600 publications, the authors concluded that train integrity monitoring in Europe is currently essentially based on axle counters (AC) and track circuits (TC), so these two concept classes of the status quo were chosen. In addition, the authors identified three main classes of possible future TIMSs: distributed acoustic sensing (DAS), end-of-train device (EOT) and digital automatic coupling (DAC).

Hereafter, the writers expound the selected five concept classes for TIMSs:

Axle counter (AC): For this concept, wheel sensors are installed at both ends of a block section to count entering and leaving wheels. An evaluation unit calculates the vacancy of that block section by subtracting those numbers [4].

Track circuit (TC): To realise a TC, a voltage is applied to both rails. Consequently, the presence of a railway vehicle leads to short circuit via a wheel set. The TC detects that short circuit and thus the vehicle meaning the occupancy of the block section. To separate TC from one another, rails can be isolated or alternating current of different frequencies can be used [4].

Distributed acoustic sensing (DAS): Generally speaking, DAS is also referred to as the application of special methods of Fibre optic sensing (FOS) and thus sometimes termed FOS [5]. For DAS, a fibre optic cable is laid along a railway track. Into that cable, laser light is pulsed from one end and reflected within the cable by natural impurities. This reflection behaviour is influenced by sound waves perpendicular to the cable caused by a moving train. This allows the train to be located by evaluating temporal changes in the reflection pattern at the laser source end of the cable [6].

End-of-train device (EOT): An EOT is a unit that is fitted to the end of the last vehicle after a freight train has been assembled. That unit comprises a telematics unit for communication with the locomotive and, e.g., a sensor unit for localisation, see [1], [7].

Digital automatic coupling (DAC): This concepts means the supplanting of screw couplings with DACs and thus realises a continuous electrical line in freight trains [8].

3 Results

In this results section, the authors discuss the advantages and disadvantages of the five concept classes for TIMSs. The discussion is based on the aforementioned literature research and is elucidated in the following by the authors:

Axle counter (AC): This concept class offers the advantage of its many years of probation and the possibility of long fixed section lengths. At the same time, the need for fixed section lengths is a significant disadvantage [4] in connection with the high costs [1].

Track circuit (TC): TCs, like ACs, have proven themselves over many years [4]. Nevertheless, they also cause considerable costs [1] and the fixed section length is even more limited [4].

Distributed acoustic sensing (DAS): This concept class offers different advantages like the detection of unequipped objects [1], the use of partially existing cables [9], the renunciation of a migration for vehicles and the possibility of continuous monitoring. By contrast, there are disadvantages such as the inability to detect stationary and difficulties to detect slow-moving vehicles [1], the problems to recognise axes and to select among parallel tracks [1], [6], the susceptibility to influences from neighbouring road traffic and the costs for the operation and maintenance of a DAS system.

End-of-train device (EOT): EOTs can offer various benefits such as the renunciation of realising extensive changes to vehicles or infrastructure, the capability to be implemented quickly without a lengthy migration strategy, the opportunity to be implemented relatively inexpensively, and the possibility to quickly replace modules in the event of a fault. Nevertheless, there are disadvantages such as potential difficulties with the energy supply, the potentially technically challenging communication with the locomotive, reliable pairing with the right train, reliable attachment at the end of the last vehicle, and restrictions in the selection of sensors compared to a conventional railway vehicle.

Digital automatic coupling (DAC): The realisation of the DAC would result in a continuous electrical line in freight trains as an ideal basis for train-sided integrity monitoring. In addition, the DAC would enable various logistical functions such as automated coupling and offer added value for rail freight transport. The biggest disadvantage of the DAC is the high investment costs, which experts estimate at EUR 6.6 to 8 billion for a Europe-wide migration of around 485,000 railway carriages and around 17,000 locomotives. In addition, a migration strategy would be required for a period with two different coupling systems in Europe [8].

4 Conclusions and Contributions

In this final section, the authors draw a conclusion and elucidate the contributing aspects of the present publication.

As a first aspect, the authors draw the conclusion that ACs and TCs are certainly track vacancy detection systems that have been proved in practice over many years, but that the costs will be too high in the distant future. In addition, these two conventional track vacancy detection systems, in contrast to the three newer concept classes, require fixed block section lengths, which the authors believe will limit capacity in the long term and led technical innovations towards ETCS level 3 become more difficult.

In the opinion of the authors, the ideal solution for rail freight transport in the long term is certainly the introduction of the DAC, but the very high investment costs and a possible Europe-wide migration are associated with considerable political risks. The authors see still considerable disadvantages with DAS so that results of further research are of high interest. So, the authors currently give the solution class EOT the best chance of being realised in the relatively short term. From the authors' point of view, the low migration effort is a factor that distinguishes this solution class as a bridge class to the DAC.

The contribution of this publication is a comparison of concept classes for possible future TIMSs. During their literature research in recent years, the authors could not find any comparable work in which possible future main solution classes for the integrity monitoring of freight trains are presented and compared with each other. Researched publications either focus on a single approach, are not considered from the perspective of train integrity monitoring, or lack a comparative character. Since the authors attach great importance to this research field, they would like to close this gap with the present work.

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